



# Quantum Artificial Intelligence and NASA

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# The QuAIL Group

Eleanor Rieffel

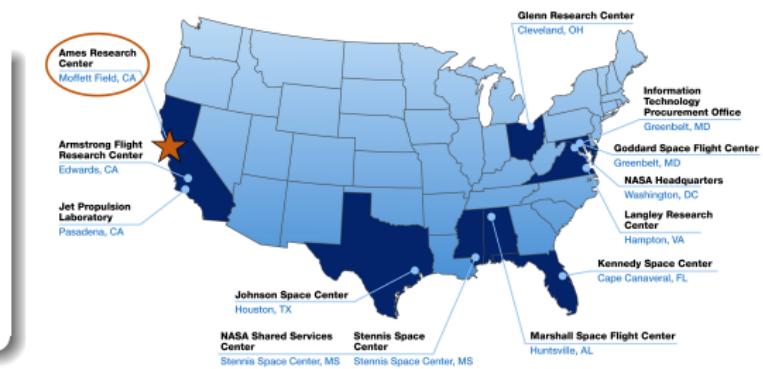
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active interns

## NASA QuAIL Mandate

Determine the potential for quantum computation to enable more ambitious and safer NASA missions in the future.



# What is and isn't Quantum Computing

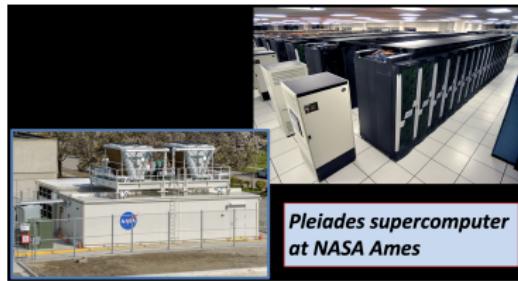
- Quantum computers do many fewer operations per second than classical computers
- They cannot solve NP-hard problems
- They are not on the verge of solving useful problems
- They can provide insight into classical solutions
- Quantum communication is not faster than light



- Quantum computers utilize additional operations
- They can decrease computational scaling for some problems
- They are programmable with limited quantum knowledge

# Why Quantum Computing at NASA

- NASA confronts computational challenges and bottlenecks with missions, limiting scopes and aims



Even if every atom on earth were a processor, we could not run some quantum-able computations classically

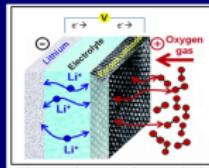
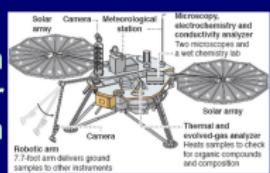
- Quantum computers offer a more efficient option
- We have a zoo of existing applications
- Near-term is a lot more heuristic
- This is potentially **Green**, with lower energy consumption

# Quantum Ready Applications at NASA



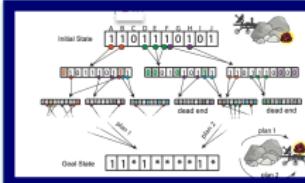
Quantum ML for Earth Science Data Analysis

Resource Allocation and Scheduling for Space Exploration



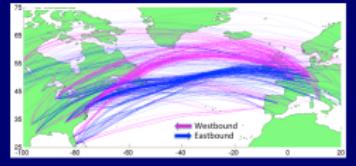
Quantum Simulations for Aerospace Materials

Secure Airspace Communication



Quantum Optimization for Mission Planning & Coordination

Air Traffic Management



The goal is never to just quantum-ify something. We seek **better** solutions in terms of time-to-solution or quality-of-solution

# How we Approach Quantum Problems



## Physics Insights

Fundamental research, Hardware co-design

## Classical Solvers

Quantum-inspired Classical Algorithms, HPC Quantum  
Circuit Simulators

## Quantum Tools

Error Mitigation, Compiling

## Quantum Algorithms

Quantum Algorithm Design, Hybrid Approaches

## Applications

Scheduling, Material Science, Machine Learning

## Communication

Quantum Networking, Cryptography

# Quantum Supremacy

- Quantum Supremacy: completing a task on quantum hardware that cannot be done with existing classical compute power
- Achieved by a Google – NASA – ORNL collaboration
- The task was mathematical and not at all practical
- We have long term applications but are on the hunt for short term applications
- QuAIL is focused on hybrid approaches



F. Arute et al. (2019),  
"Quantum supremacy using  
a programmable  
superconducting processor",  
Nature 574, 505-510

# Collaboration with Industry

- The QuAIL group strives to provide a bridge between academic research and industry



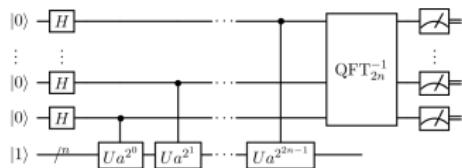
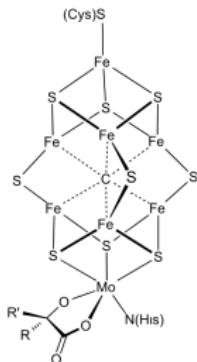
- Assess Google's quantum hardware
- Develop calibration and noise modeling approaches
- Collaborate on quantum supremacy
- Collaboration with government as well: DARPA projects and DOE NQI centers (SQMS and C2QA)
- Assess Rigetti's quantum hardware
- Collaboration on the DARPA ONISQ program
- Collaboration as part of a DOE NQI center

# The Hunt for Near-Term Algorithms and Applications

## Noisy Intermediate Scale Quantum (NISQ)

100-10000 qubits, circuit depths in the thousands, no error correction

- We have algorithms for the long term

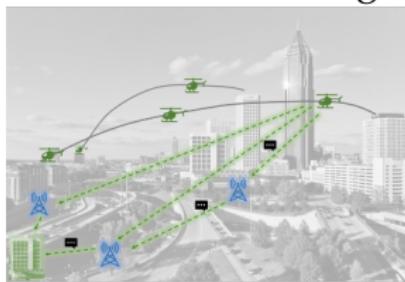


- For the short term, we expect quantum chemistry and materials to be useful

- A lot of our near-term algorithms are heuristic.
- We have hope for optimization (can get square root speed up)

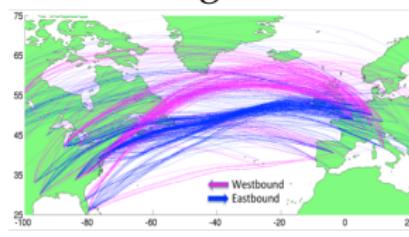
# Quantum Computing for Aeronautics

## Quantum algorithms to optimize information sharing in bandwidth-limited autonomous settings



Z. Izquierdo et al. (2022), The Advantage of pausing: parameter setting for quantum annealers, Phys. Rev. Applied 18, 054056, 2022

## Quantum annealing approaches to de-conflict optimal trajectories for air traffic management



T. Stollenwerk et al. (2020), Quantum annealing applied to de-conflicting optimal trajectories for air traffic management, IEEE Trans. Intell. Transp. Syst. 21, 285-297

## Feasibility of QIS to address cybersecurity of communication availability for air traffic of the future



N. Cramer et al. (2020), Enhanced UAS availability via vehicle-to-vehicle routing scaled experiments, AIAA Aviation Forum, 2020-2850

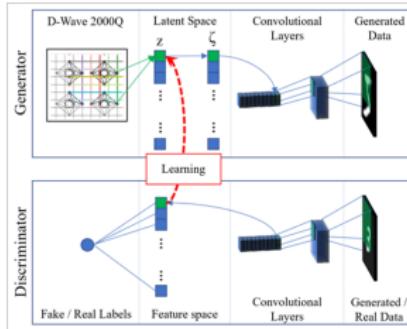
# Quantum Computing for Earth Science

## Quantum-assisted variational autoencoder for similarity search in MODIS datasets



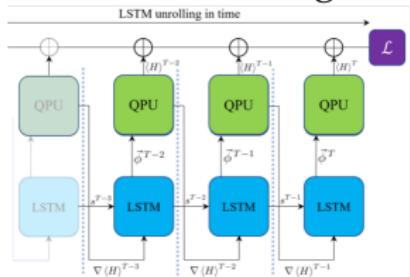
N. Gao et al. (2020), High-dimensional similarity search with quantum-assisted variational autoencoder, KDD '20, 956-964

## Quantum-assisted associative adversarial network



M. Wilson et al. (2019), Quantum-assisted associative adversarial network: Applying quantum annealing in deep learning, arXiv:1904.10573

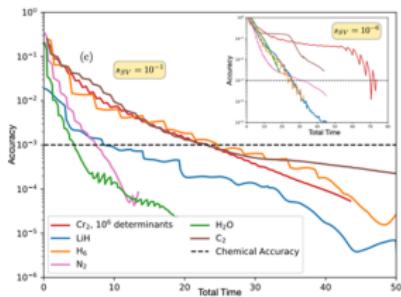
## Optimizing quantum heuristics with meta-learning



M. Wilson et al. (2019), Optimizing quantum heuristics with meta-learning, arXiv:1908.03185

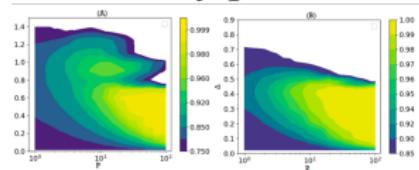
# Quantum Computing for Materials

Quantum phase estimation to measure ground and excited state energies



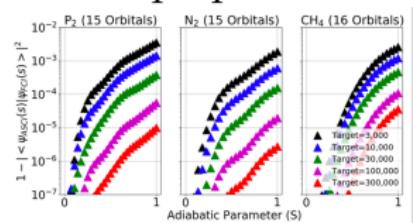
K. Klymko et al. (2021), Real time evolution for ultracompact Hamiltonian eigenstates on quantum hardware, arxiv:2103.08563

Quantum Alternating Operator Ansatz (QAOA) to find ground states in quantum chemistry problems



V. Kremenetski, et al. (2021) Quantum Alternating Operator Ansatz (QAOA) Phase Diagrams and Applications for Quantum Chemistry, arXiv:2108.13056

Speeding up adiabatic state preparation

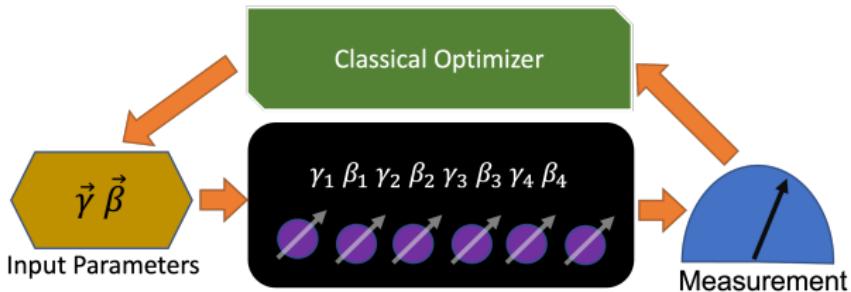


V. Kremenetski, et al. (2021), Simulation of adiabatic quantum computing for molecular ground states, arXiv:2103.12059

# Variational Quantum Algorithms

## Hybrid Algorithms

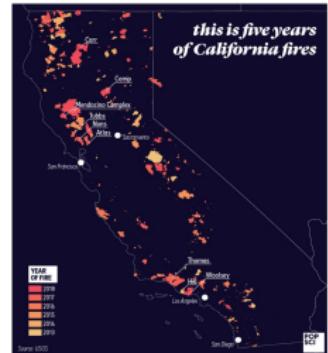
Algorithms that rely on both quantum and classical components



- Often involves classical outer loop optimization of variational parameters
- This naturally evolved into Quantum Machine Learning

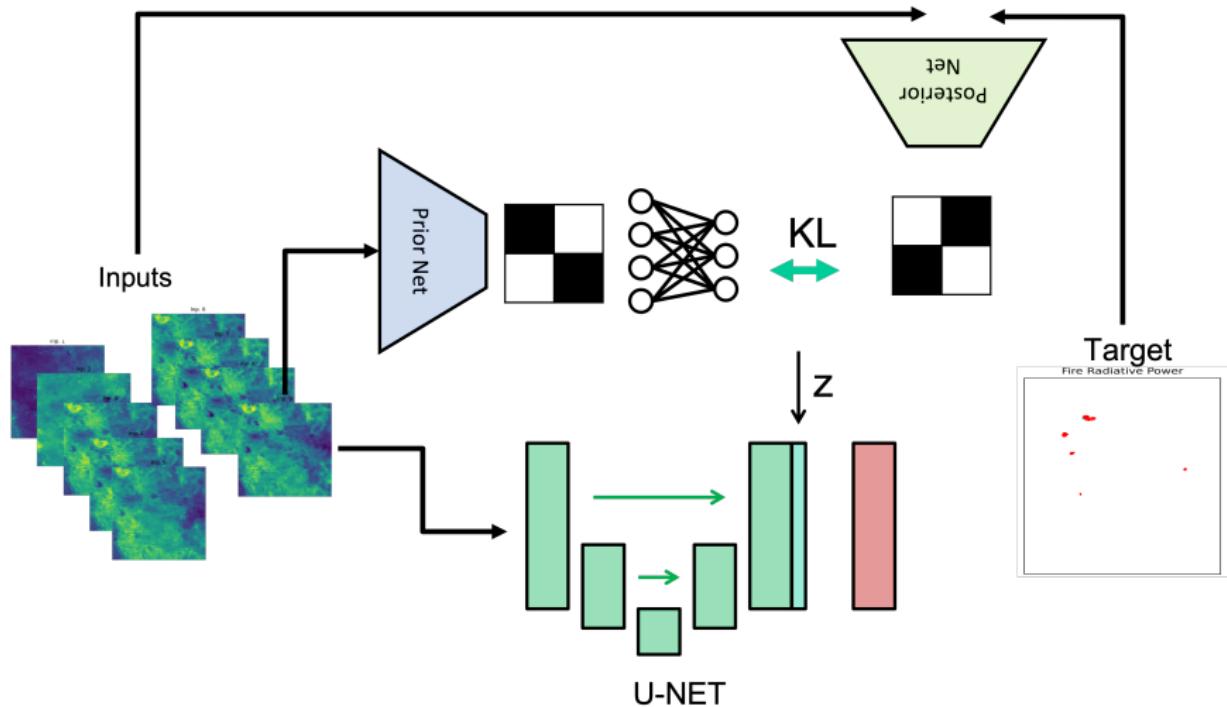
# Problem Setup

- We want to use quantum machine learning to analyze satellite imagery
- We are focusing on wildfires and vegetation properties that indicate risks
- We want to create a quantum-assisted image-to-image translation algorithm
- We are starting with quantum-ready models and incorporating quantum where available
- Focus on Quantum Variational Autoencoder and later on Quantum Neural Networks



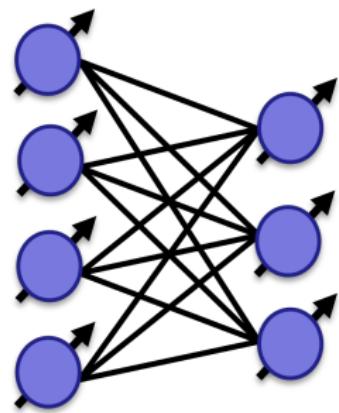
Credit: USGS

# U-Net and Variational Autoencoder (Training Mode)

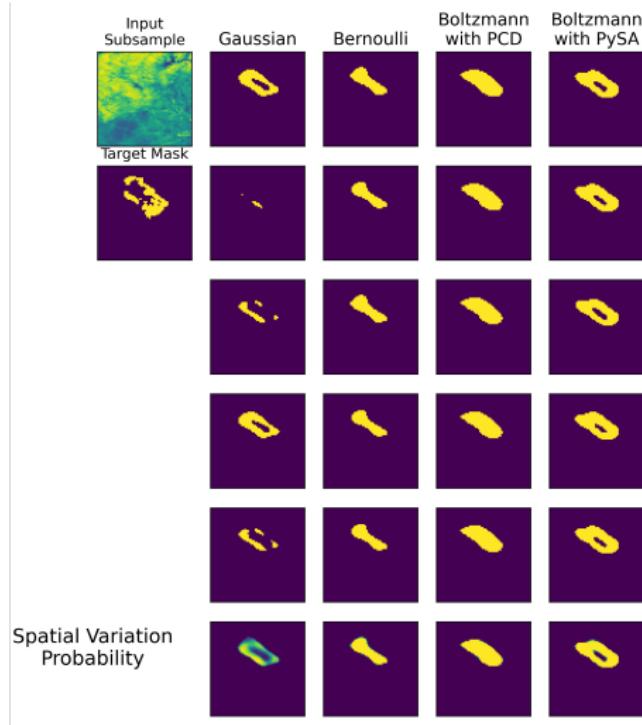


# Quantum Latent Space

- The latent space is small and so the best place to plug in a small quantum computer
- We are using a Quantum Ising Born Machine (QIBM)
- The QIBM is the same connectivity as a Boltzmann machine but with quantum instead of thermal fluctuations
- The quantum computer automatically importance samples
- Training of a Born Machine is possible and relies only on easy to produce quantum measurements



# Initial Results and Efforts

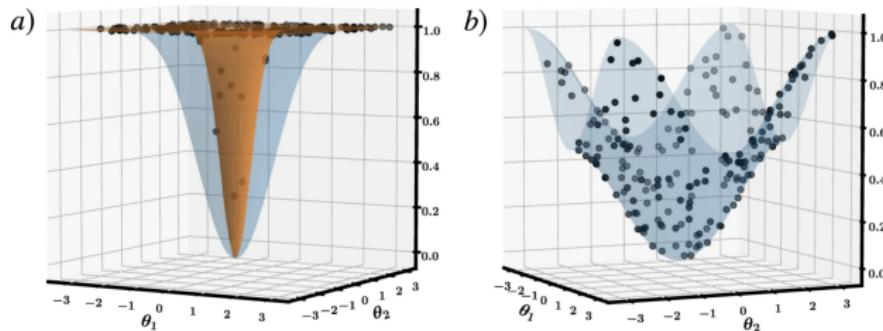


# Problems and Hurdles with QML

- Quantum systems are currently small and noisy
- Avoiding hype and finding problems with useful advantage

## Barren Plateaus

Regions of the control landscape where the gradients of our variational parameters are decreasing exponentially with system size



Cerezo, M., Sone, A., Volkoff, T. et al. Cost function dependent barren plateaus in shallow parametrized quantum circuits. Nat Commun 12, 1791 (2021).

# Reasons to Hope in QML

- Quantum computers will only get bigger (10-20 years till the technology really matures)
- Even a square root speed up can be a lot
- This is producing novel results in classical computing as well
- Try it and see: this is a novel and more powerful computing paradigm that will soon be testable at scale
- The People: quantum information is highly interdisciplinary, and it is already bringing together disparate expertise

# Thanks

	<p>Eleanor Rieffel</p> <p>Lucas Brady</p> <p>Zoe Gonzalez Izquierdo</p> <p>Aaron Lott</p> <p>Jeffrey Marshall</p> <p>Nishchay Suri</p> <p>Zihui Wang</p>	<p>David Bernal Neira</p> <p>Shon Grabbe</p> <p>Filip Maciejewski</p> <p>Gianni Mossi</p> <p>Norman Tubman</p> <p>active interns</p>
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<p>Ata Akbari Asanjan</p>		

The AIST program, DARPA, DOE Centers

